DRILLING AND COMPLETION OF THE URACH III HDR TEST WELL

Dr. Udo Meier and D. I. Peter L. Ernst

Preussag AG, Erdol und Erdgas

Federal Republic of Germany

ABSTRACT

The hot dry rock (HDR) test well, Urach III, was drilled and completed in 1979. The borehole is located in Southwest Germany in the geothermal anomaly of Urach. The purpose of project Urach was to study drilling and completion problems of HDR wells and to provide a test site for a HDR research program. The Urach III borehole was drilled to a total depth of 3,334 metres (10,939 feet), penetrating 1,700 metres (5,578 feet) into the granitic basement. Extensive coring was required to provide samples for geophysical and geochemical studies. Positive displacement downhole motors were used for coring and normal drilling operations. It was found that these motors in combination with the proper bits gave better results than conventional rotary drilling. Loss of circulation was encountered not only in sedimentary rocks but also in the granite. After drilling and completion of the borehole, a number of hydraulic fracturing experiments were performed in the open hole as well as in the cased section of Urach III. A circulation loop was established by using the single-borehole concept. It is not yet clear whether new fractures have actually been generated or preexisting joints and fissures have been reactivated. Evaluation of the results of this first step is almost completed and the planning of Phase II of the Urach project is under way.

DISCLAIMER

1. Introduction

The geothermal anomaly at Urach is located in the southwestern part of the Federal Republic of Germany, about 40 km to the south of Stuttgart. It constitutes a zone of comparatively young volcanism and extends over a surface area of about 80 km^2.

The thermal anomaly at Urach was discovered almost 150 years ago. Hot water is currently being produced there from the Jurassic and Triassic strata. This is employed for medicinal purposes and - to a limited extent - for heating purposes too. The heat source of the anomaly is presumed to be a magma chamber in the crystalline basement (figure 1).

2. Objectives of the Urach research project

After the Oberrheintal-Graben, the anomaly at Urach represents the largest known geothermal anomaly in the Federal Republic of Germany. The Urach research project has the following objectives:

- The feasibility of measuring the temperature distribution within the basement by means of conventional geophysical methods is to be investigated.

- Information concerning the lateral and vertical extension of the anomaly is to be obtained; the type and position of the heat source should be more accurately delimited.

- The most important physical parameters of the rock are to be determined by means of in-situ measurements and core analyses in the laboratory, in order to make the fundamental data available for further research work.

- The feasibility of extracting energy from hot dry rocks (HDR process) is to be investigated, and the heat-reservoir parameters essential to the investigation are to be measured.

- The aquiferous properties and conditions of the Mesozoic and Palaeozoic sediments, as well as the possible rates and temperatures of production are to be investigated with the aim of utilizing the water for balneological and heating purposes in the future.

It was obvious that the drilling of a well all the way down

into the crystalline basement was necessary for achieving the desired objectives. Because of limited funds only one well could be drilled. Therefore, particularly careful planning of the Urach III well was imperative, in order to ensure that all the objectives be realized. In addition to a comprehensive coring program especially the bore hole diameter casing scheme and directional course of the bore hole were to be planned in such a way that the frac and circulation tests required for carrying out the HDR program of investigation could be conducted. In the Urach III well a system of circulation using only a single well is to be tried for the first time.

Since the geology of the deeper sediments and of the crystalline basement was only approximately known, the drilling program had to be so flexibly designed that major deviations from the available, preliminary geological profile would not jeopardize the achievement of the objectives.

Additional difficulties arose because of the exposed location of the drilling operations in a deep circular valley within an area of health resorts and recreation. Despite elaborate sound-insulating measures, certain operations could not be performed during the night or on week-ends.

3. Technical planning of the well

On the part of the contractor it was planned first to drill the Urach III well down to a depth of about 2500 m for geothermal exploration. On the basis of the preliminary geological profile and of the requirements pertaining to the coring, testing and measuring programs, the drilling and casing phases presented in figure 2 resulted. Besides the normal standard program for a deep well, which includes programs for drilling, drilling-fluid, casing and cementing, the special programs for coring, logging and testing should of course receive particular emphasis for this well.

For the purpose of drilling the well a mobile drilling rig of the Cabot Franks 900 type (figure 3) with a telescoping mast was selected by the operator, Preussag AG Erdöl und Erdgas. This rig attained a final depth of 3334 m, thus achieving a depth record for this type of rig.

The technical specifications for the rig, including the power values, are presented in figure 4. The power of the rig is distributed as follows:

- about 662 kW for the drawworks

- about 736 kW for the slush pumps
- about 184 kW for the rotary table

The entire equipment, both above and below ground was designed in accordance with the requirements of the Bureau of Mines and the technical safety regulations.

4. Course of the drilling and completion

23" Bore hole section and completion - 645 m

The drilling operations began with a bit diameter of 23" on the 3rd of October, 1977. With the use of a fresh-water-based, bentonite drilling fluid with a low content of solids and a density of 1.15 kg/l, the well penetrated Jurassic, Lias and the Upper and Middle Keuper (figure 5).

The directional course of the bore hole was constantly monitored, in part with modern Teledrift systems and Eastman instruments (figure 6).

From a depth of 488,5 m (Keuper) onward, the 23" bore hole was reduced in size to 12 1/4", for the purpose of recovering

various cores with the use of 6 3/4" x 4"double tube core barrels and 8 15/32 " core bits.

Down to the 18 5/8" casing depth a total of 3 cores were pulled, with a core recovery of about 25 m.

After widening to 23", Schlumberger measurements were performed prior to the installation of casing. After 19 workdays the 18 5/8" string of casing was inserted down to a depth of 642.4 m and cemented all the way to the surface with about 144 • 10^3 daN cement of class G (density = 1.92 kg/l).

17 1/2" bore hole down to 1082 m

After the installation of the preventer the well was drilled further down to about 700 m at 12 1/4", in order to conduct a production test on the Upper Muschelkalk with the use of a Pleuger pump. A water production of 4697 m^3, at a maximal temperature of 56.7°C, was achieved. Circulation losses were first recorded in the Upper Muschelkalk at a depth of 687 to 700 m. Despite the addition of lost-circulation material and tablets of highly viscous bentonite (density = 1.05 kg/l), a total loss of circulation occurred at a depth of 692 m. Drilling was first continued down to 700 m with lost circulation of very light drilling fluid (density = 1.03). A cement seal was

subsequently effected in the depth range between 696 and 687 m with about 12 • 10^3 daN cement of type PZ 350 F.

After this operation the well was widened to 17 1/2" and drilled further to a depth of 705 m. In order to pull 9 further cores (of which 2 were oriented) prior to reaching a depth of 1082 m, the bore hole diameter was again reduced to 12 1/4". After the performance of Schlumberger and temperature measurements, as well as the widening of the bore hole to 17 1/2", the 13 3/8" casing was landed down to a depth of 1080 m in the Buntsandstein and cemented to a depth of 520 m with 43 • 10^3daN deep-well cement of class G, blended in the dry state with silica flour.

After about 35 workdays - including all manipulations and measurements - the bore hole penetrated the Upper, Middle and Lower Muschelkalk and, from 842 m onward, the Buntsandstein before attaining the casing depth. This was accomplished with the use of eight 17 1/2" rock bits and for the predrilling, thirteen 12 1/4" rock bits. With the four C-20 diamond core bits employed during this phase of the drilling (Rotliegendes and Carboniferons), a good service life was achieved and 14 cores were pulled, with a core recovery of about 81 m.

12 1/4" drilling phase - 1810 m

It was first necessary to wait until curing of the cement, installation of flanges, measurements conducted by Geologisches Amt für Bodenforschung, Hannover, and the changing of the equipment for blowout prevention (12"; 5000 lb/in^2 ram and Hydril preventer) had been completed. During the subsequent 12 1/4" phase of the drilling, the Buntsandstein was further penetrated with a drilling fluid of low density; beginning at 930 m, the Rotliegendes was drilled. Down to a depth of 1586 m further 4" cores were pulled with the use of a 6 3/4" x 4 double-tube core barrel. Again, core bits of type C-20, or else of types C-23 and C-24, were employed. Comprehensive temperature measurements were conducted at this depth (figure 7).

In the hard andin part highly abrasive crystalline basement the coring operations proceded with extreme difficulty. Substantial core losses and rapid wear of the diamond core bits sometimes occurred. In order to improve the stability of the coring tool an 8 1/2" bore hole was predrilled. Moreover special, very hard, impregnated core bits were obtained for this application from a service company. These measures resulted in longer service life and improved core recovery. For the first time in

this well, a double-tube core barrel was installed below a 6 3/4" down-hole motor (Navi-Drill^{R}). With the use of C-24 core bits two cores 9 m in length and one core 4 m in length were pulled at an average penetration speed of 1.9 to 2.9 m/h. In comparison to conventional rotary coring the drilling progress was enhanced by up to 100 %. The following data were obtained with the use of the 6 3/4" Navi-Drill^{R}:

- pumping rate about 1100 l/h
- pressure drop about 32 bar
- rotary speed about 250 min^{-1}
- torque about 1500 Nm
- drilling thrust 5 to 6 · 10^{3} daN

After very severe circulation losses at a depth of 1777 m in the crystalline basement, the drilling operations in the 12 1/4" phase were first interrupted at 1810 m. Open hole straddle tests with an anchor shoe were then performed in the range 1779 to 1759 m. Subsequently cement seal operations were effected in the loss zones between 1679 to 1810 m; six bottom cementing operations were thereby performed with the use of class G cement mixed in the dry state with silica flour. The 9 5/8" liner was installed down to a depth of 1808 m in the crystalline basement with the

use of a Hydro-Liner hanger. The 9 5/8" liner head is situated at a depth of 980 m. The cementing of the liner was effected with $31.5 \cdot 10^3$ daN class G cement. The position of the cement heas was located at a depth of 1025 m by means of temperature measurements.

In the Carboniferous and the upper crystalline basement insert bits were used for drilling through hard and abrasive formations at an average penetration speed between 0.5 and 1.5 m/h.

8 1/2" drilling phase - 3334 m (final depth)

On the 12th of March, 1978 the well attained the maximal depth of 2500 m in the crystalline basement during the 8 1/2" drilling phase, as originally specified in the contract. In compliance with the wishes of the Geologische Landesamt für Bodenforschung an extension of the drilling contract was negotiated, whereby the final depth of the Urach III well was increased to 3350 m.

During the further penetration of the crystalline basement high drilling torque values occurred at times. After repeated reaming and round trips, the bore hole finally attained its final depth of 3334 m after 105 workdays; it was subsequently surveyed by Schlumberger. In the formation, which is in part very hard and

abrasive, thirty-six 8 1/2" rock bits (insert bits) were used. At a bit load of 13 to 15 · 10^3 daN a rotational speed of 50 to 90 min^{-1},and pumping rates of 1000 to 1300 l/min the penetration speed amounted to 0.6 to 1.7 m/h. During the entire 8 1/2" drilling phase a fresh-water-based bentonite drilling fluid with a density of 1.1 to 1.15 kg/l was employed.

During this phase of the drilling a total of 22 core with an overall cores recovery of 119 m was pulled, with the use of twelve C-24 core bits (figure 8).

Prior to the installation of the final 7"casing, diverse pumping tests were conducted on the uncased bore hole below 1808 m, as well as on sections behind the 9 5/8" and 13 3/8" casing after the corresponding perforation. This was followed by a large number of straddle tests, pressure and temperature measurements, as well as subsequent cementing operations on the bore hole.

On the 12^{th} and 13^{th} of July, 1978 the final 7"casing was installed; it was cemented in two stages from 3320 to 900 m: In the range from 3320 to 1600 m, class D deep-well cement with silica flour was used; in the range from 1600 to 900 m, Pozmix special cement with a density of 1.6 was used.

The casing string was designed with a collapse resistance for 0.14 bar/m, as shown in figure 9, wereby the casing is assumed to be empty.

As shown by the plot of time versus depth (figure 5) the following periods were required for the various drilling phases, including coring operations, pumping and other tests, casing operations, temperature measurements, and Schlumberger measurements:

for the

23" drilling phase, about 20 workdays
17 1/2" drilling phase, about 36 workdays
12 1/4" drilling phase, about 48 workdays
8 1/2" drilling phase, about 104 workdays

This gives a total of 208 workdays, not including the installation and cementing of casing, waiting periods, etc.

In conclusion it can be stated that all drilling operations for the Urach III well were successfully completed and that practically no fishing jobs were necessary during the entire course of the project.

5. Logging and testing

Temperature measurements were constantly performed during the drilling phases. A series of well logging operations served to

determine the various petrophysical and reservoir parameters. Furthermore several drill stem tests were conducted, in order to ascertain the influx from various horizons. Production tests were conducted with the use of electrically driven centrifugal pumps.

Fracing was performed in both uncased and cased sections of the well; in this way a circulation system was successfully constructed. This work has already been described in detail elsewhere.

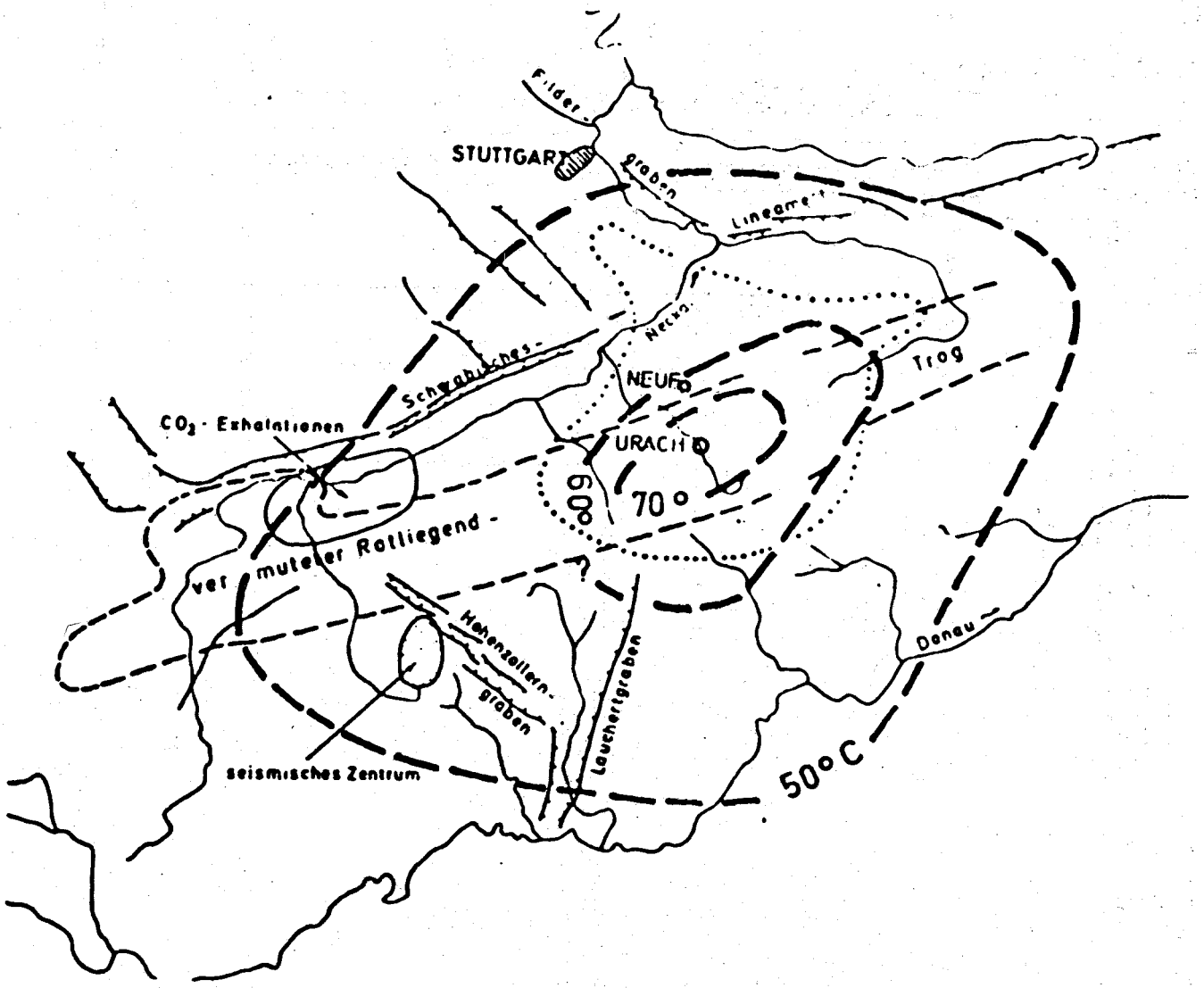

Fig. 1

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NEUFFEN-URACH
GEOTHERMAL ANOMALY
(AFTER K. SCHÄDEL)

Bearb.
Zeichn.

Pr. 1

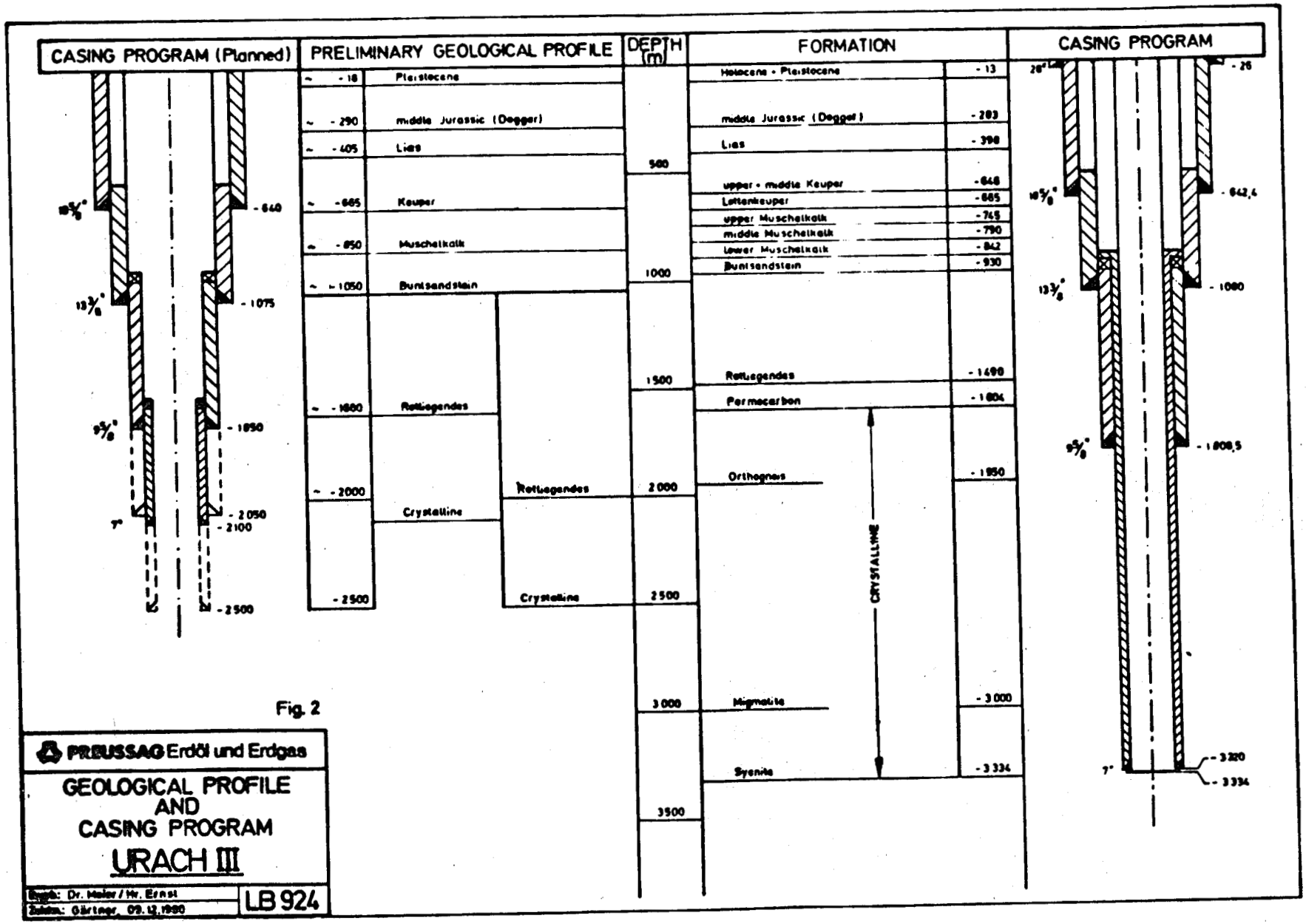

Fig. 2

PREUSSAG Erdöl und Erdgas

GEOLOGICAL PROFILE AND CASING PROGRAM

URACH III

Engb.: Dr. Meier / Hr. Ernst
Zeichn.: Gärtner, 09.12.1980

LB 924

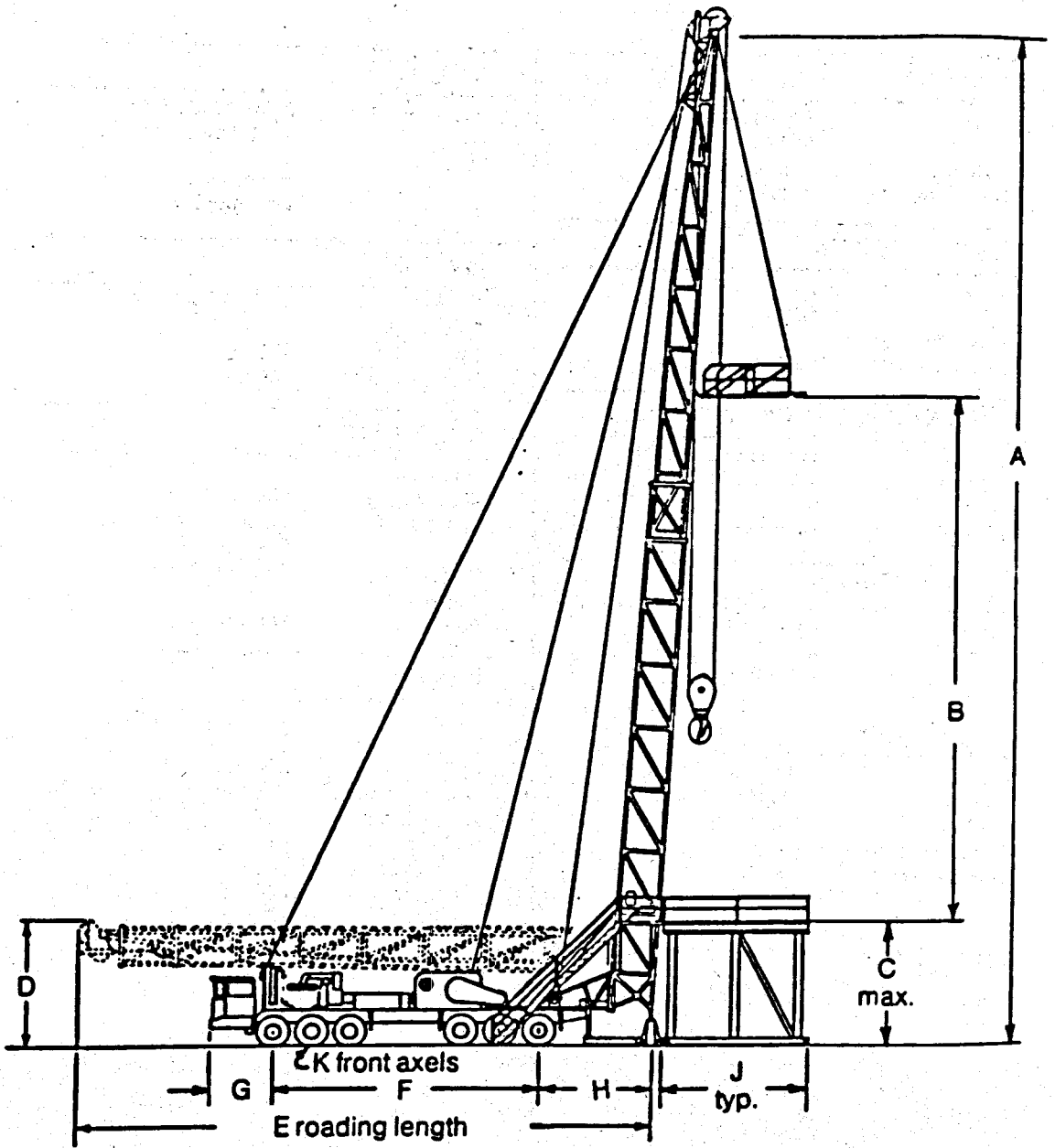

Fig.3

PREUSSAG Erdöl und Erdgas

DRILLING RIG

CABOT FRANKS 900

Bearb.:

Zeichn.

Pr. 1

Technical Specifications Cabot - Franks 900

Derrick

Type	: Franks 900
Height	: 34.14 m
Reg.hook load	: 1422 kN
Max.hook load	: 1628 kN

Substructure

Type	: Cabot
Height	: 4.58 m
Max.rotary-table Sup.capacity :	1560 kN

Travelling Block and Hook

Type :	McKissick 667-250
Max. load :	2207 kN
Sheaves :	5
Reeving :	10-times

Rotary Table

Type :	National C-275
Opening :	25 ½"
Max.drivetab. :	250 RPM

Drawworks

Type :	Franks Model 2346
Input :	662 kW
Max. line pull :	230 kN
Max. line speed :	13.7 m/sec
Line diameter :	1 ⅛"

Mud Pump

Type :	Wirth 7 ¼"x12"/500
Unit :	2
Input :	368 kW
Pumping rate :	2000 l/min
Pressure :	100 bar - 7 ¼"
	192 bar - 5"

Engines

Type :	2 Cat D343 TAJ
	1 MTU 8V 331 TC 31
Unit :	3
HP :	Cat 276 kW
	MTU 368 kW

Swivel

Type :	LA 200 Cont. EMSCO
Stat. load :	1780 kN
Dyn. load :	1201 kN
Max. pressure :	350 bar

Mud Tank

Number :	7
Mud mixing :	Mission 6" x8 "
Shale shaker :	Siebtechnik Double Deck Shaker
Desander :	Pioneer 12 x 4"
Desander - Pump	: Mission 6" x 8 "

Bop

Type	: 20" Hydril/Shaffer
Unit	: 3/3
Pressure	: 350 bar
BOP closing unit :	Koomey BOP T20-160-3S
Accumulator Volume	: 629 l
Procharge Pressure:	207 bar
Number	: 1 12" x 5000 Hydril
	1 12" x 5000 Shaffer-Double

Fig.4

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CABOT FRANKS 900

Bearb.

Zeichn.

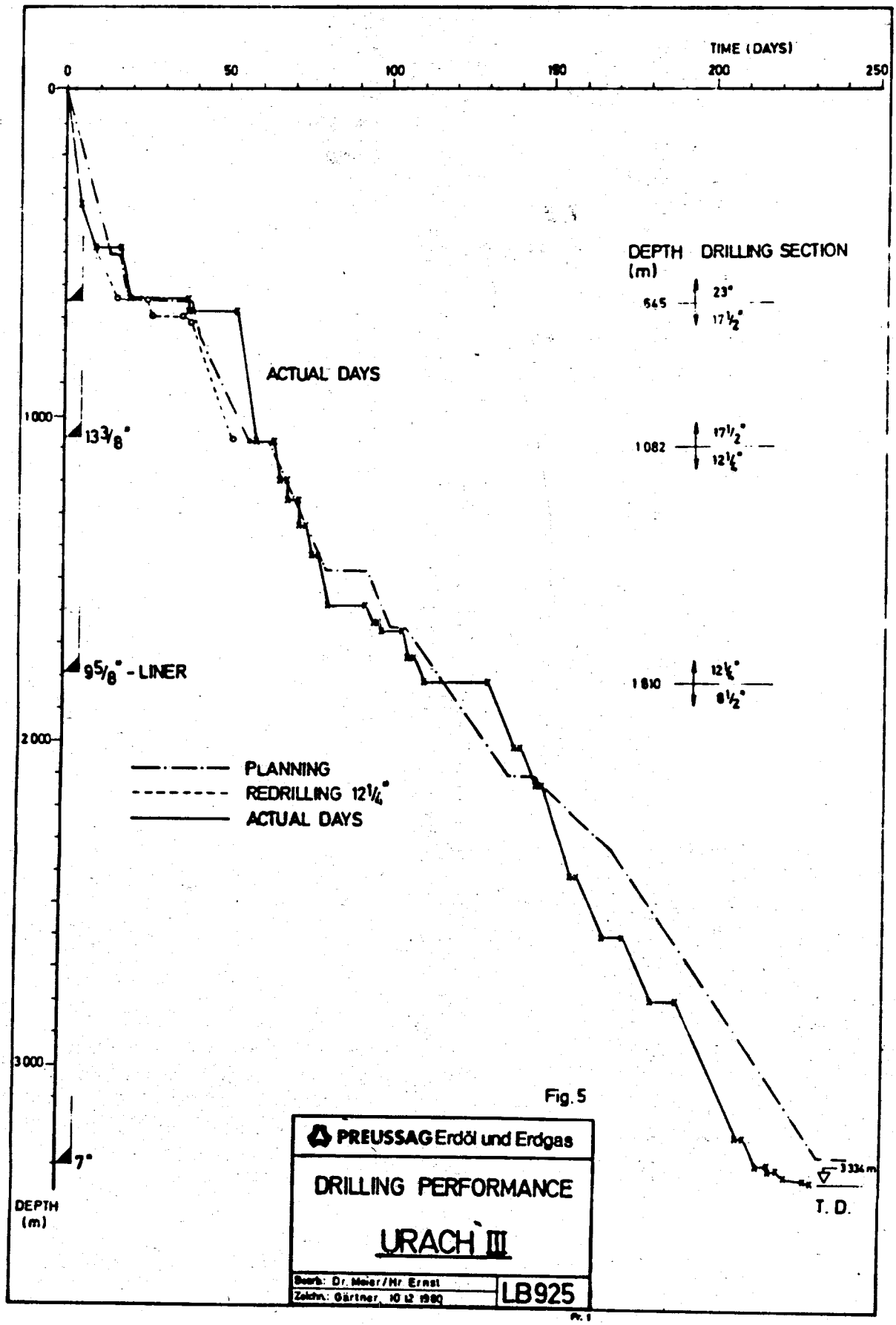
TIME (DAYS)
0
50
100
150
200
250
DEPTH DRILLING SECTION
(m)
545
23°
17½°
1082
17½°
12¼°
1810
12¼°
8½°
ACTUAL DAYS
1000
13 3/8"
9 5/8" - LINER
2000
PLANNING
REDRILLING 12¼"
ACTUAL DAYS
3000
7°
3334 m
T. D.
DEPTH
(m)
PREUSSAG Erdöl und Erdgas
DRILLING PERFORMANCE
URACH III
Bearb: Dr. Meier/Mr Ernst
Zeichn.: Gärtner, 10 12 1980
LB925

Fig. 5

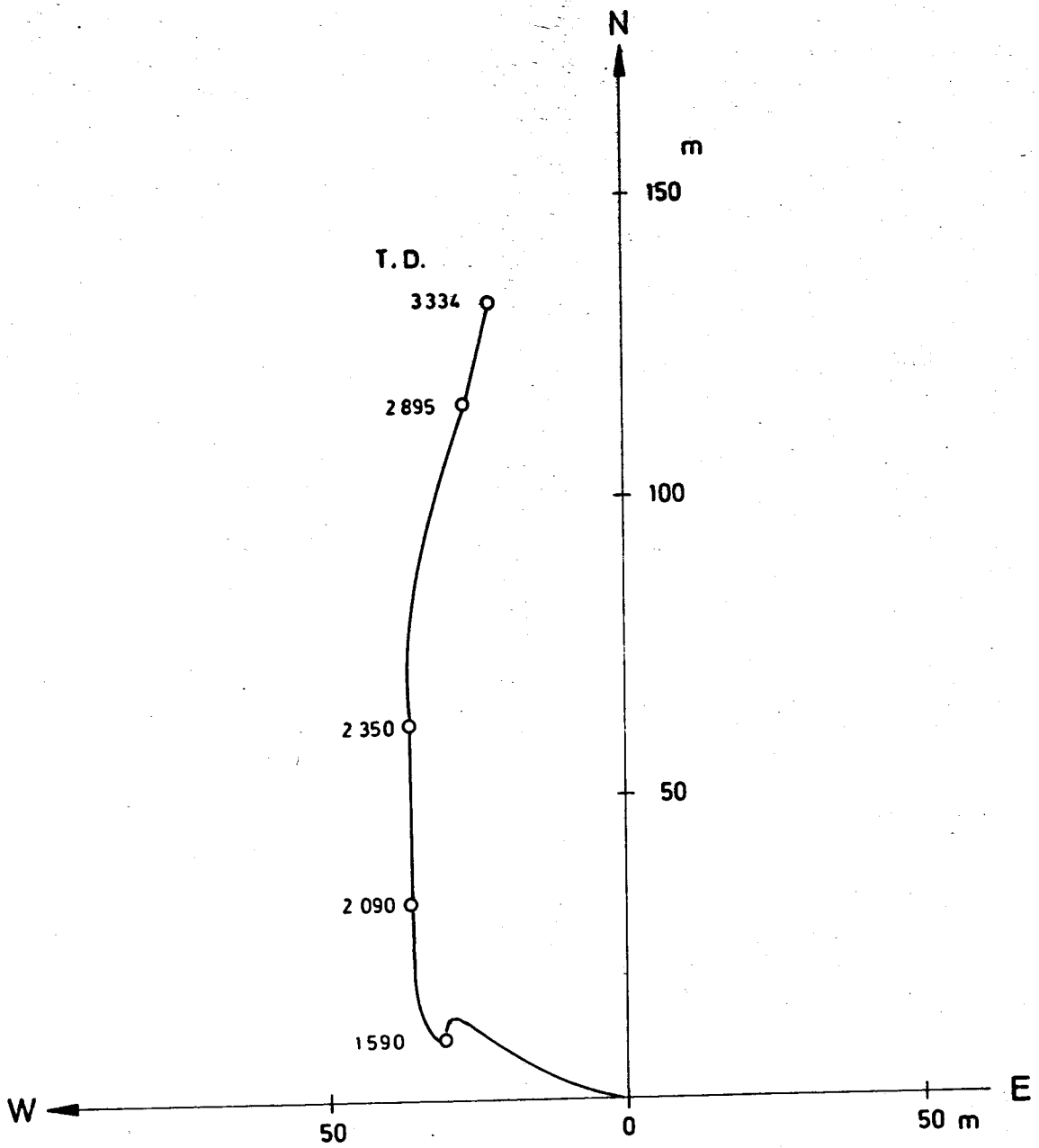

Fig.6

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HORIZONTAL - PROJECTION
OF
URACH III

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Zeichn.: Gärtner 09.12.1980

LA673

Pr. 1

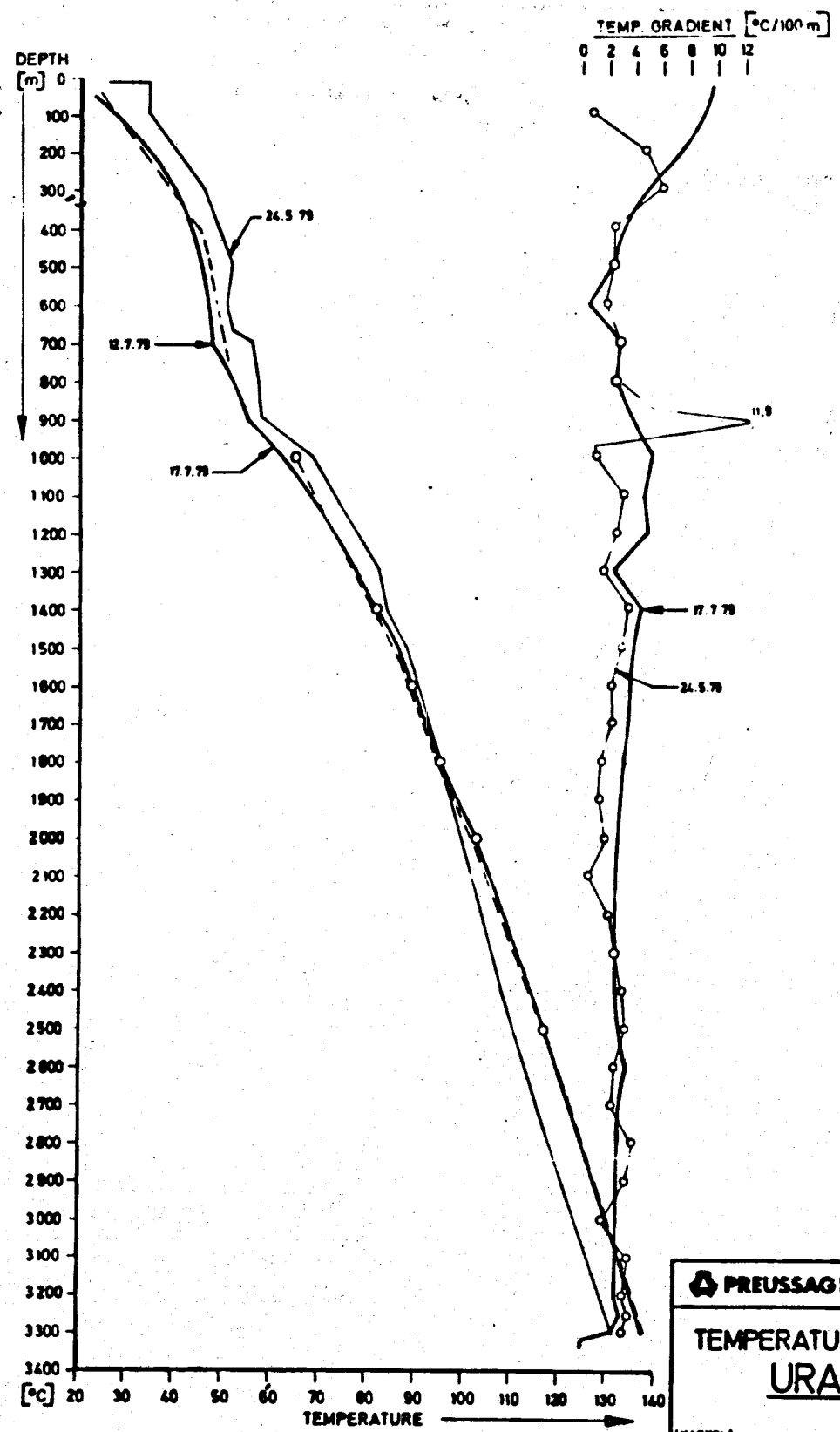

Fig. 7

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TEMPERATURE-PROFILES

URACH III

(HAERBEL)

Bearb.: Dr. Meier / Hr. Ernst

Zeichn.: Gärtner 04.12.1980

LB 922

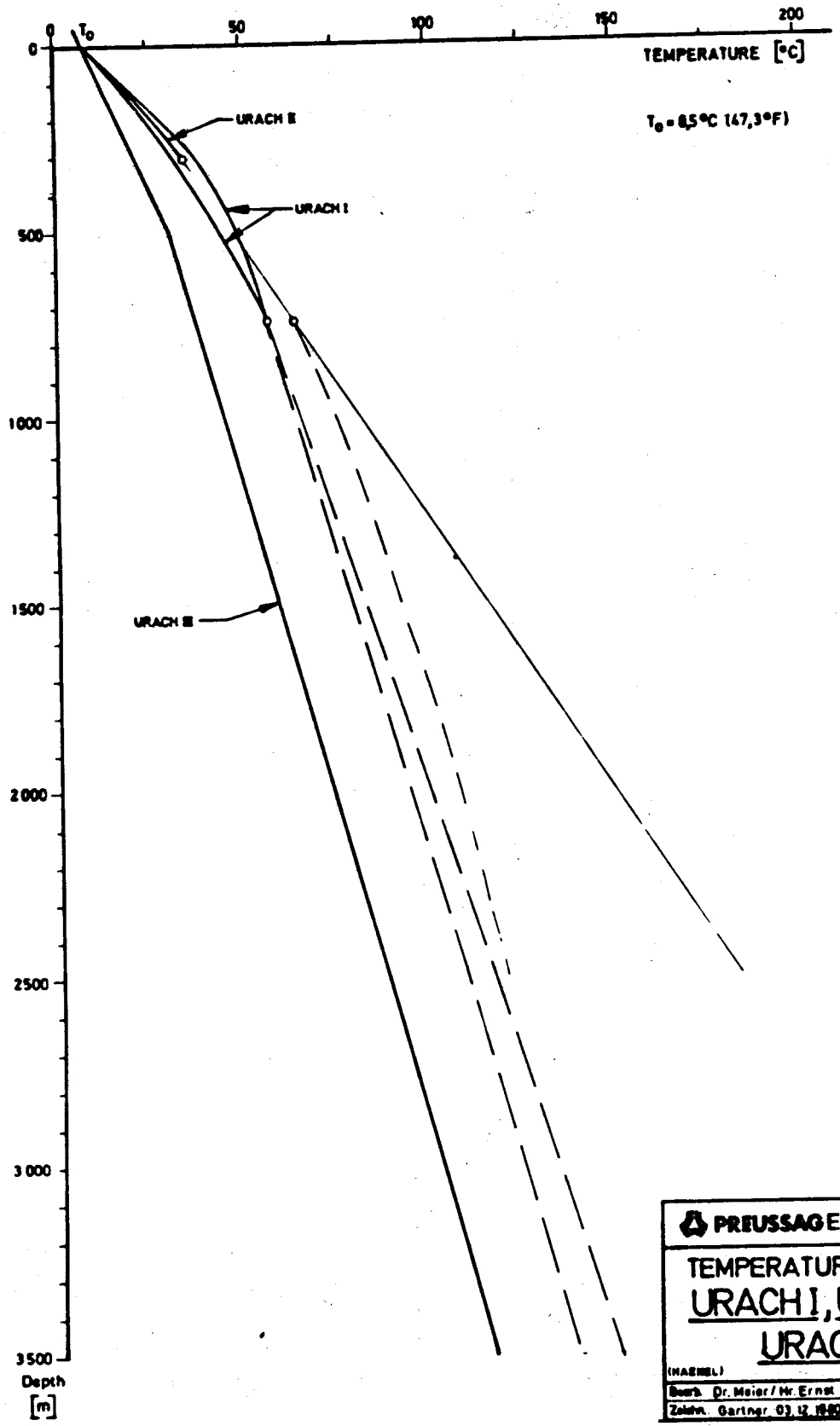

Fig.7a

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TEMPERATURE-PROFILES
URACH I, URACH II,
URACH III

(HAEMEL)

Bearb. Dr. Meier / Hr. Ernst
Zeichn. Gartner 03.12.1980

LB 923

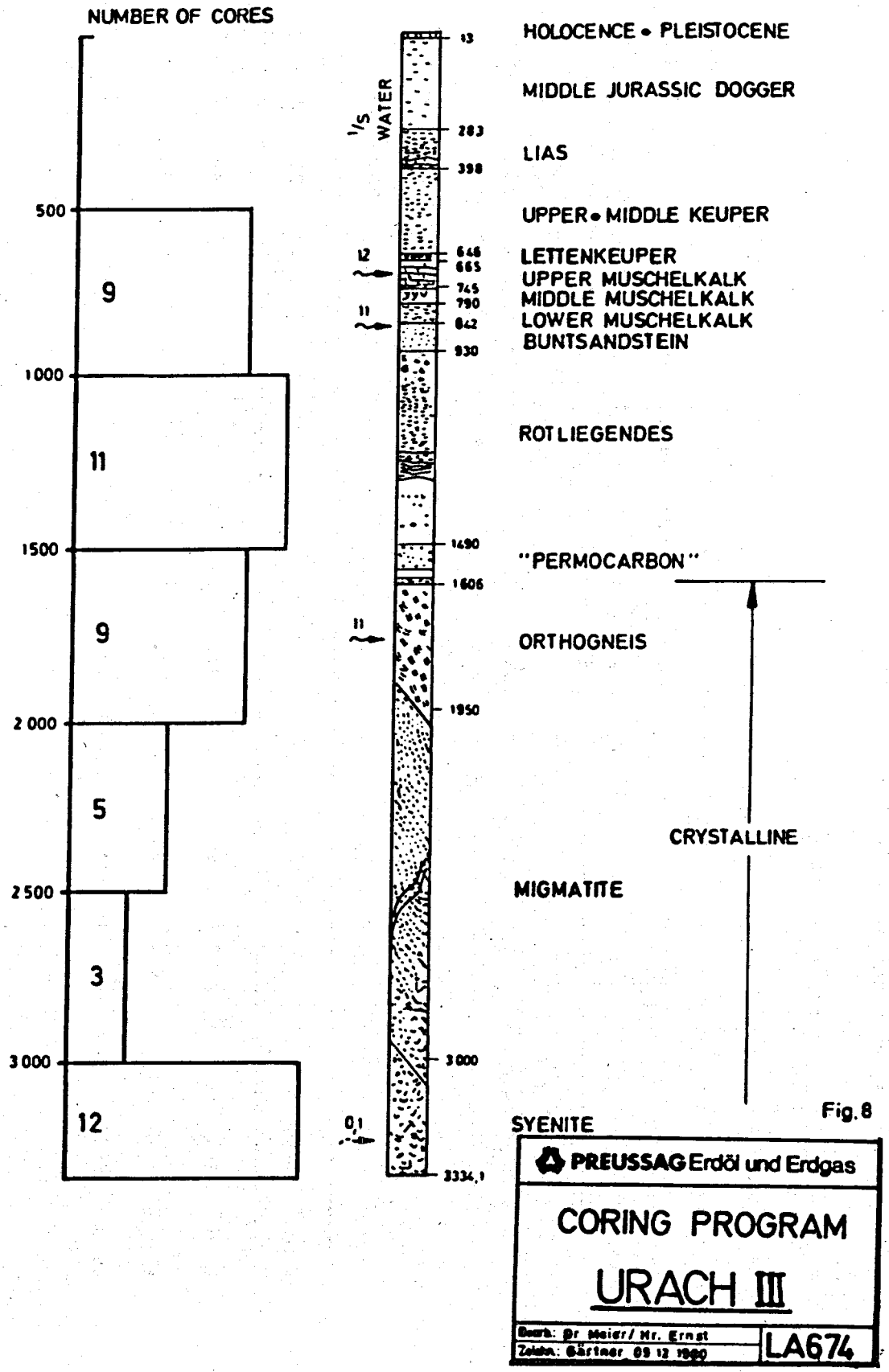
NUMBER OF CORES
500
1000
1500
2 000
2500
3000
9
11
9
5
3
12
l/s
WATER
12
11
11
0,1
13
283
398
646
665
745
790
842
930
1490
1606
1950
3000
3334,1
HOLOCENCE • PLEISTOCENE
MIDDLE JURASSIC DOGGER
LIAS
UPPER • MIDDLE KEUPER
LETTENKEUPER
UPPER MUSCHELKALK
MIDDLE MUSCHELKALK
LOWER MUSCHELKALK
BUNTSANDSTEIN
ROTLIEGENDES
"PERMOCARBON"
ORTHOGNEIS
CRYSTALLINE
MIGMATITE
SYENITE
PREUSSAG Erdöl und Erdgas
CORING PROGRAM
URACH III
LA674

Fig. 8

T E C H N I C A L P L A N N I N G C A S I N G D E S I G N

P R E U S S A G AG U R A C H 3 1 9 7 8

CASING OD in	NOM. WEIGHT lbs/ft	GRADE	JOINT TYPE	DEPTH from m	DEPTH to m	m	WEIGHT Mp	WEIGHT TOTAL Mp	Pc bar	Pcred bar	Pi bar	Pi/1.1 bar	Pj JOINT Mp	Pj CAS. Mp	S
								0.0		61					
18 5/8"	96.5	K-55	STC	0.0	642.0	642.0	83.1	83.1	61	56	173	157	409	690	4.9
								0.0		134					
13 3/8"	68.0	K-55	STC	598.0	1080.0	482.0	48.0	48.0	134	126	238	216	325	484	6.7
								48.0		99					
13 3/8"	61.0	K-55	STC	0.0	598.0	598.0	53.7	101.8	106	91	213	193	287	436	2.8
								0.0		139					
9 5/8"	36.0	K-55	STC	980.0	1808.5	828.5	43.9	43.9	139	125	243	220	191	255	4.3
								0.0		484					
7"	29.0	N-80	EXL	2533.0	3320.0	787.0	33.6	33.6	484	455	563	511	326	306	9.0
								33.6		455					
7"	29.0	N-80	LTC	2445.0	2533.0	88.0	3.7	37.4	484	451	563	511	270	306	7.2
								37.4		344					
7"	26.0	N-80	LTC	0.0	2445.0	2445.0	94.5	132.0	373	248	499	453	235	273	1.7

Fig.9